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ABSOLUTE SCALES OF PHOTOGRAPHIC AND PHOTOVISUAL MAGNITUDE

By Frederick H. Seares

MOUNT WILSON SOLAR OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

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The first extensive photometric investigation undertaken with the 60-inch reflector has been the determination of absolute scales of photographic and photovisual magnitude for stars near the North Pole. Although the instrument is best adapted for the observation of objects fainter than the tenth magnitude, it can also be used for the brighter stars; and it thus becomes possible to secure, on a uniform system of color, results covering the entire range of stellar brightness at present known.

In any photometric problem involving the use of photographic methods, there is serious difficulty in evaluating the functional relation connecting the intensity of the light acting on the plate with the observed photographic effect. The photographic process is too complicated and too sensitive to slight fluctuations in the conditions which determine its action to permit of the application of anything like a general relation; and it is necessary to standardize or calibrate the images appearing on each plate which is to contribute toward an absolute scale.

Besides photographic difficulties, there is another which is serious, namely, that encountered in all physical observations involving the comparison of quantities which, relatively, are very large and very small. In the present case, the range of brightness actually covered in the determination of the photographic scale is about $17\frac{1}{2}$ mags.; the intensity ratio for the brightest and the faintest of the stars observed is therefore of the order of 1 to 10,000,000, and consequently the opportunity for an accumulation of error in passing from the one extreme of brightness to the other is great.

The methods commonly employed for the standardization of the photographic effect in terms of intensity have as their principle the production of two series of images with a known variation of the intensity between the exposures. This in itself is not easily accomplished, at least with assurance of freedom from systematic error. A variation of the total energy by a change in the exposure time immediately introduces the photographic difficulties that we wish to avoid; a change in the intensity by a reduction of the aperture changes the diffraction pattern of the optical image, and it is not a priori certain that the same quantity of energy distributed over different patterns produces the same photographic result; the use of a coarse objective grating or screen of wire gauze is unobjectionable from the standpoint of diffraction, but requires a troublesome laboratory investigation for the determination of its constant; the diversion of a certain fraction of the light into a secondary image by means of a prism of small angle is subject to disturbances by diffraction and absorption. Other methods are subject to similar uncertainties; and, in addition, all which involve successive exposures upon the same plate, like the majority of those just enumerated, have to contend with irregularities in the atmospheric conditions.

In arranging the program of observations it was considered that the latter could be disregarded, because of the favorable situation of Mount Wilson and the moderate exposure times which would be required. Moreover, the considerable accumulation of material necessary for the investigation would render atmospheric disturbances wholly accidental. Other difficulties, it was hoped, would be sufficiently controlled by the use of a wire gauze screen and a series of circular diaphragms covering a wide range of aperture. For the latter, the following diameters in inches were adopted: 40, 32, 14, 9, 8, and 6. Two large screens of wire gauze were used, one of single thickness and one of double thickness, the wires of the latter being crossed at an angle of 45°; smaller screens for use over the diaphragms of 14 inches and less were also available. The constants depend upon laboratory determinations of the absorption for point sources, controlled by the measurement of the absorption for surfaces.

It was found convenient to separate the investigation into three parts, with a corresponding variation in the treatment: (*a*) bright stars, including objects brighter than the tenth magnitude; (*b*) intermediate stars, from the tenth to the eighteenth magnitude; (*c*) faint stars, fainter than the eighteenth magnitude. The limits refer to the photographic scale.

For both scales the work was begun with the second group—the intermediate stars. The details of observation, measurement, and reduction have been described elsewhere.[1] For the photographic scale, to which the following paragraphs refer, the exposure times fall into two groups, one of 11 minutes or less, the other ranging between 30 minutes and 60 minutes. Forty-two separate determinations of the scale were derived from the data on 15 plates of shorter exposure; from those of longer exposure there were fourteen determinations, from an equal number of plates. The former series involved the use of the single-thickness screen, 60 inches in diameter, and the 32, 14, 8, and 6-inch diaphragms, besides two other arrangements of less importance.

For the interval 10.5–17.6, the mean of 17 scales with the 32-inch diaphragm is practically identical with that of 10 found with the 14-inch diaphragm. The 5 scales with the two smaller diaphragms show a deviation of about 1% from the mean of all, and there is a similar divergence between the results for the wire gauze screen and the mean for all the diaphragms. The agreement is therefore such as to leave little doubt as to the negligible character of the diffraction effect and the satisfactory elimination of other errors.

The longer exposure plates, which in several cases reach the nineteenth magnitude, were all obtained with diaphragms of either 32 or 14 inches, and are likewise satisfactorily accordant. These plates also give results for the brightest of the intermediate stars; in other words, they overlap completely the region covered by the plates of shorter exposure. The average difference between the mean scales from the two series, derived from nine groups of stars between 10.6 and 16.8, is 0.015 mag. There seem, therefore, to be no systematic errors which depend upon the exposure time.

The determination of the scale for the two remaining groups—faint stars and bright stars—presupposes a knowledge of that for the intermediate group. Here again the methods have been fully described elsewhere,[2] and only a very brief statement need be included here.

The extension to the fainter objects was by means of plates which, with one exception, received two exposures, both with the full aperture of 60 inches, but with different exposure times; the longer exposure was four or five hours, the shorter approximately half an hour. The reduction was based upon the empirical relation established by Kron,[3] which expresses the law of photographic action. Strictly speaking, the process involves an extrapolation, but one which is fairly reliable. The accordance of the six plates for the faint stars is scarcely less satisfactory than that of the long-exposure diaphragm plates used for the intermediate stars. The limiting photographic magnitude thus reached is about 20, which may be taken as the faintest attainable, under favorable conditions, with an exposure of four hours.

Owing to the small field of the reflector, and the relatively wide distribution of the bright stars, these objects had generally to be observed individually. They were photographed with screens or diaphragms producing images comparable with those of stars between the tenth and fifteenth magnitudes, obtained with the same exposure but without screen or diaphragm. The following is a typical arrangement of the exposures, which were 2 minutes each: (1) intermediate stars, full aperture; (2) bright star with reduction of intensity, usually three or four exposures with different arrangements of diaphragms and screens; (3) intermediate stars, full aperture. The magnitudes of the reduced-intensity images were found by comparison with those of the intermediate stars, which had already been investigated; the subtraction of the reduction constants then gave values for the real magnitudes.

The method possesses many advantages and, when applied with sufficient elaboration, apparently gives a scale of high precision. For example, suppose that a screen absorbing 6 mags. is used. Since standards between the tenth and fifteenth magnitudes are presupposed, bright stars between magnitudes 4 and 9 are within reach; and since in each case the same constant is subtracted from the magnitude of the reduced-intensity image, the slope of the resulting scale will be independent of any error affecting the constant. The process is, in effect, a transference of the adopted scale for the intermediate stars to the region of the brighter objects.

To provide the necessary checks, it is desirable that all possible arrangements of apertures, covering a wide range of reduction constants, should be used. There will thus be accumulated a number of separate, but overlapping, determinations of the scale, each of which should be homogeneous with that of the intermediate stars; their intercomparison controls the errors of the constants, and their mean is the final result. When the data are extensive, as is here assumed, the reductions can be modified so that the result is no longer dependent upon that for the intermediate stars.

To keep the labor within reasonable limits, this part of the investigation was restricted to the stars of the North Polar Sequence, the brightest of which is Polaris; but in order that there might be a satisfactory connection with the intermediate group, a number of the latter were reobserved by the bright-star method. These considerations led to the selection of 32 objects distributed between magnitudes 2.5 and 12.3, photographic. More or less complete series of observations were obtained with 10 different arrangements of the aperture, besides partial series for several others, the constants ranging from 1 to 11 mags. The overlapping scales, which are based upon 213 plates and 662 individual magnitudes, are in good agreement; not only are they sensibly parallel, but the constant systematic differences are small, which indicates that the reduction constants are well determined.

With the completion of the investigation of the bright stars, it became possible to reduce the entire series of results to the international zero point. This was accomplished by making the mean brightness of the white stars near the sixth magnitude equal to the mean of their visual magnitudes in *Harvard Circular*, No. 170, proper allowance for spectrum being made for those objects not of type AO.

The resulting catalogue of photographic magnitudes includes 617 objects, the great majority of which are fainter than the tenth magnitude. All of the latter are close to the Pole of 1900, and among them are included the stars of the Polar Sequence. To these special attention has been given, although a large number of other stars have well determined magnitudes, based on ten or more individual values. The very faint objects, which are relatively numerous, are naturally subject to greater uncertainty.

The treatment of the data for the photovisual scale was exactly the same as that outlined above for the photographic scale. Although only 6 plates were used for the intermediate and faint stars, the precision is much greater than one would thus be led to expect. Owing to the better definition of the images on the isochromatic plates, the probable error of a photovisual magnitude is only two-thirds that of a photographic result. The photovisual scale for the bright stars, which depends upon 122 plates and 367 individual magnitudes, is probably quite as reliable as the photographic scale in the same region. Final photovisual magnitudes were obtained for 339 stars between magnitudes 2.1 and 17.5.

The average deviation of a single photographic magnitude, including the scale error of a plate over a range of 8 or 9 magnitudes is 0.125 mag.; the corresponding photovisual result is 0.087 mag.

About 300 stars have had both their photographic and photovisual magnitudes determined, and, in consequence, color indices for these are available. These confirm a result announced at an earlier stage of the work, namely, that the faint stars are all relatively red. For the bright stars, we have small, and even negative, color indices in large numbers. At the seventeenth photovisual magnitude the smallest value is 0.6 or 0.7 mag., the lower limit gradually increasing as the fainter stars are approached. This phenomenon is undoubtedly of very great significance, but its interpretation cannot at present be given with certainty. It is evident, however, that the determination of star colors will form an important part of stellar investigations in the future.

This last consideration only emphasizes the necessity of precision in the magnitude scales, for any relative error enters to its full amount into the color index, and thus vitiates the results of comparisons involving stars of different degrees of brightness. In the present case a supplementary investigation provided an important control.

Hertzsprung has determined by an entirely different method—that of effective wave-lengths—the colors of nearly 200 stars in the cluster N. G. C. 1647. These can be expressed as color indices and compared with similar results derived directly from photographic and photovisual magnitudes. The agreement or disagreement of the two series of values immediately checks the relative errors of the scales.

To execute this comparison, the polar scales were transferred to the region of the cluster by 10 plates of duplicate exposure—5 for each scale. All possible care was taken to avoid errors in the zero points, for uncertainties here also enter to their full amount into the color indices.

In this manner color values were obtained for about 50 stars between magnitudes 11 and 14.5, which had also been observed by Hertzsprung. There is some uncertainty involved in the transformation of the effective wave-lengths into color indices; but it is not likely that the mean difference in the two series of values exceeds a tenth of a magnitude, and there is some evidence that it is even less. The relative errors of the scales between the sixth magnitude, which defines the international zero point, and the thirteenth or fourteenth magnitude can therefore scarcely exceed this limit.

Comparisons of the individual scales for the Pole with the results of other observers are also important in their indications. The only other investigation covering the entire range of brightness is that of the photographic scale carried out at the Harvard Observatory. With proper allowance for color, the Harvard and Mount Wilson results are in close agreement, that is, the scales are parallel, from the tenth to the fifteenth magnitude. For the fainter stars there is a large divergence, which has arisen from differences in the method of reduction (the Harvard scale for the fainter stars is based upon Mount Wilson plates). For the bright stars there is also a divergence, amounting to about 6%, whose origin is not yet fully explained.

Other investigations of the photographic scale have been made at Greenwich and Potsdam. These extend from the ninth to the sixteenth or seventeenth magnitude; after correction for color to reduce to the system of the reflector, both show a close accordance with the Mount Wilson results. In addition, the bright stars between the fourth and eighth magnitudes have been observed at Göttingen and at the Yerkes Observatory. These results are also in close agreement with the Mount Wilson scale.

The material for the photovisual scale is less abundant. Visual magnitudes of the Polar Sequence stars have been determined at Harvard as far as the fourteenth magnitude. This scale intersects the Mount Wilson photovisual scale at the sixth and the twelfth magnitudes, but at other points there are important differences, some of which are obviously due to color. Further, the *Yerkes Actinometry* contains photovisual magnitudes as far as 7.5. The Mount Wilson results agree satisfactorily with these, and there is also good accordance with the visual magnitudes of Müller and Kempf. Beyond this no results have as yet been published, although others are in preparation. A detailed comparison with all these various investigations will be included in forthcoming papers in the *Astrophysical Journal*,[4] which will also give fuller details and a summary of the numerical results for the Mount Wilson scales. The complete discussion will appear as Volume 3 of *Papers of the Mount Wilson Solar Observatory*.[5]

[1] *Mt. Wilson Contr.* No. 80; *Astrophys. J.*, 39, 307 (1914).

[2] *Ibid; Mt. Wilson Contr.* No. 70; *Astrophys. J.*, 38, 241 (1913).

[3] *Potsdam Publ.* No. 67.

[4] *Mt. Wilson Contr.* Nos. 97, 98, 102; *Astrophys. J.* (In press.)

[5] *Publications of the Carnegie Institution of Washington.*

MITOSIS IN TRICHOMONAS

By Charles Atwood Kofoid and Olive Swezy
ZOOLOGICAL LABORATORY, UNIVERSITY OF CALIFORNIA

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The process of cell-division in the simpler Protozoa is significant in its relation to the evolution of nuclear and extra-nuclear structures. The behavior of the extra-nuclear organelles in unicellular organisms during the process of binary fission is significant as to the origin and relationships of such structures as flagella, blepharoplast, and axostyle. One of the distinctions between the Ciliata and the Flagellata has been held to be the direction of the plane of division, transverse in the former, longitudinal in the latter; therefore all reported cases of transverse division in Flagellata should be critically inspected.

Observations on mitosis in *Trichomonas augusta*, a flagellate parasitic in the digestive tract of amphibians (*Diemyctylus torosus Rana boylei*, and *Bufo halophilus* from California, and *Rana pipiens* from Chicago) enable us to make a fuller correlation of mitosis in the Flagellata with that in the Metazoa, to correct or supplement the observations of others regarding mitosis in trichomonad flagellates, and to establish on ample morphological grounds the essentially longitudinal nature of their division. Our conclusions have been verified in all essential features, in